Coastal Eco-Waters: Adapting for a Resilient Campus

Florida International University

Team Registration Number: **M11**

Team Members:
Civil Engineering: Vivek Verma (Team Lead)
Environmental Engineering: Angeluz Lozada
Hydraulic Engineering: Linlong Bian
Landscape Architecture + Environmental & Urban Design: Alain Carrazana, Rutusha Nagaraj
Mechanical Engineering: Sumit Zanje
Ocean Engineering: Aditia Rojali
Water Resources Engineering: Dogukan Ozecik
Public Policy and Administration: Ana-Maria Dimand

Faculty Advisors:
Arturo S. Leon, Department of Civil and Environmental Engineering
Ebru Ozer, Department of Landscape Architecture + Environmental & Urban Design

FIU Facilities Coordinator: Stuart M. Grant

Abstract:

The Florida International University Biscayne Bay Campus (FIU-BBC), with its 1.4-mile coastal edge, is an ideal site for the planning and implementation of sustainable stormwater management practices. Existing campus buildings and infrastructure are already at risk, given rising seas. Current stormwater management practices fail to fully address the needs of the delicate ecosystems on and around the campus. Water quality and benthic life in bordering Biscayne Bay Aquatic Preserve are greatly dependent upon and affected by surface runoff. Future developments planned for the campus, habitat loss caused by urbanization, rising seas, and frequent storms are important factors we took into consideration during design development. Working closely with the FIU-BBC Facilities Department, our team addressed three key issues that will mitigate flooding and stormwater pollution, reduce heat-island effect, and conserve water while adding recreational, educational, and aesthetic values to the campus. These key issues are to eliminate 25-yr return period rainfall flooding projected for the 2050 NOAA sea-level rise scenario, minimize pollutant discharge to the Bay, and maximize rainwater reuse. The proposed green infrastructure includes five interconnected permeable wetlands, green roofs, vertical gardens, urban tree canopy, permeable walkway, rainwater harvesting tanks, and a lined storage wetland. Irrigation needs of the proposed tree canopy are supplied from the lined wetland. An automated siphon system, developed by our team, transfers water from the lined wetland to the tree canopy. The proposed green infrastructure solutions can serve as a model for coastal universities and communities facing similar challenges due to sea-level rise.

1. Introduction

FIU-BBC sits on the northwestern edge of the Biscayne Bay, which is connected to the Atlantic Ocean. The campus is surrounded by mangrove forests on the north, northeast, and west, and the Biscayne Bay Aquatic Preserve on the south and southeast. The heart of the campus is a series of linked mangrove channels that connect to the Biscayne Bay, allowing some filtration of polluted stormwater runoff. FIU-BBC is threatened by sea-level rise. With just a three-foot rise in sea level, the western part of the campus will be inundated, along with the single-entry road onto campus. The goals of this project are to create filtration gardens and wetlands to capture, detain, and bio-remediate stormwater runoff from impervious areas, primarily parking lots and roofs, providing sustainable irrigation, and improving the quality of stormwater before it enters the Biscayne Bay.

Throughout the planning and design phases of the project, we used the FIU 2010-2020 Campus Master Plan as a reference to ensure all proposed initiatives are aligned with the Master Plan. The goals of the Master Plan, which are directly related to our proposed solutions, are listed below:

- Retrofit existing campus buildings with water-saving devices
- Improve the integration of existing and new stormwater retention areas as landscape enhancement elements
- Protect natural stormwater management and the hydrological areas from contamination
- Improve water quality
- Interconnect water bodies to maximize capacity
- Reduce the use of potable water for the irrigation of the landscape by increasing the use of harvested gray water
- Re-design the existing pervious walkways with canopy shading
- Comply with water quality standards for discharge to the two mangrove channels
- Create landscaped areas, gardens, and natural habitats to promote conservation

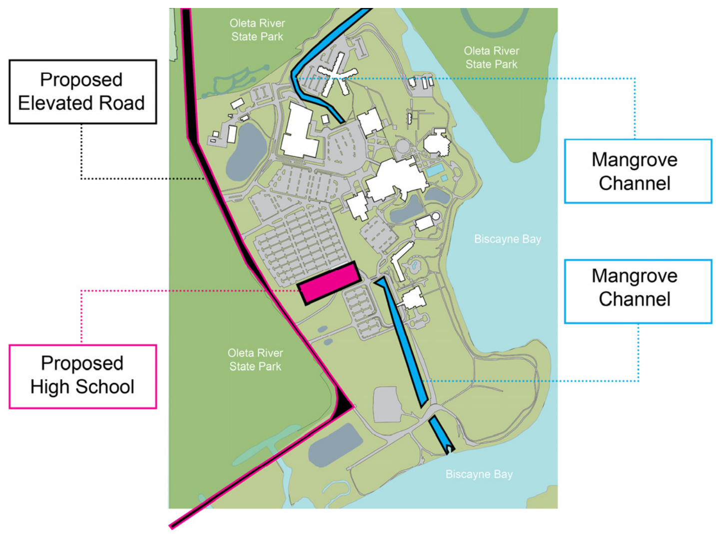

Figure 1. Overview of the FIU-BBC Campus showing existing conditions and projected near-future conditions. Buildings – White; Water bodies – Blue; Mangrove Preserve and Grass Fields - Green; Body of water at entry (top), Central parking area (middle), main parking area (bottom) - Gray. Based on LIDAR data, the existing retention ponds approximately can hold 15,223 m^3 (12.34 acre-ft), 4,540 m^3 (3.68 acre-ft), and 8,349 m^3 (6.77 acre-ft) water, assuming an average depth of 1.5m (4.9ft).

Besides using the FIU-BBC 2010-2020 Campus Master Plan, we also worked closely with the FIU Facilities Department. As a result of our interaction with the FIU Facilities, we were informed of a near-term project to elevate the existing Biscayne Boulevard 1m (3.3ft), which would provide access to the campus (Figure 1). Also, according to the FIU-BBC 2010-2020 Campus Master Plan, a new high school facility will be built on the lowest area of the campus indicated in Figure 1. Prior to the construction of the new high school, the area will be filled to avoid inundation due to onsite runoff and seawater seepage.

To receive feedback from the users of the proposed project, we performed onsite surveys to delineate the perceptions of the FIU-BBC students, staff and faculty in terms of aesthetics and recreational uses. The results of the surveys are shown in Figure 2, where the spaces identified as enjoyable, neutral, and non-enjoyable are circled in green, yellow, and red and the circle diameter is correlated with the counting of the responses.

2. Existing Conditions and Site Challenges

2.1 Site Description

The FIU-BBC is located in North Miami, Florida, at the edge of the largest estuary on the southeast coast of Florida, called Biscayne Bay. The campus is a peninsula surrounded by water and is bordered by Australian pines and a mangrove nature preserve on the west side. Due to its location and low-lying elevation, the campus is prone to flooding caused by king tide events, prolonged heavy rains, storm surge, and also sea-level rise. Other critical issues include salt-water intrusion due to the over-extraction of groundwater from the Biscayne Aquifer and degradation of Biscayne Bay habitats caused by polluted runoff.

Currently, the campus has only one entry/exit road that is only 3 feet above mean high sea level. Porous limestone and sand are present immediately under the thin topsoil layer, which allows seawater seepage. This single entry/exit road passes through a developing area, where new high-rise buildings are being built.

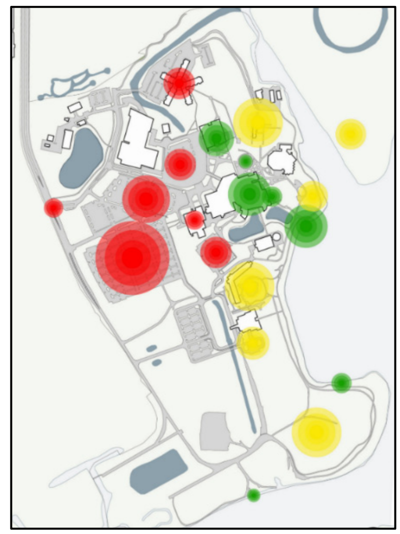

Figure 2. User survey results. Red circles (not enjoyable spaces), yellow (neutral), and green (enjoyable).

As shown in Figure 1, there are two mangrove channels that receive surface runoff from the surrounding impervious areas and direct it into the Biscayne Bay. Mangroves within the channels provide limited runoff treatment due to short detention time. Three varieties of mangroves can be found on campus; red, black, and white. The mangroves capture carbon, reduce coastal erosion, establish deep and fast-growing roots, and they are salt-tolerant (Kitheka, 1997). Deep mangrove root systems capture nitrates, phosphates, and other runoff pollutants, which enter the Biscayne Bay from the parking lots. FIU-BBC is also adjacent to the coral reefs near Haulover Inlet, and seagrasses at the outlets of the mangrove channels. Mangroves, seagrasses, and coral reefs are known to protect the coastline and interact with one another through the exchange of energy in the form of dissolved organic matter and faunal migration (Kitheka, 1997).

The existing retention ponds on campus collect surface runoff from the surrounding watersheds. The retention ponds have no lining, allowing direct infiltration of surface runoff into the groundwater through the porous limestone substrate. During high tides, however, the tidal flow pushes brackish water into the ponds due to seawater seepage. With increased sea-level rise, the capacity of existing ponds to hold stormwater runoff will decrease.

2.2 Slow and Rapid Onset Hazards Affecting the Site

As an oceanfront environment, FIU-BBC is vulnerable to threats from slow-onset hazards (e.g., sea-level rise), and rapid onset hazards (e.g., hurricanes and storm surge). Moreover, due to porous limestone beneath the campus grounds, the FIU-BBC will suffer from seawater seeping from underground as the sea level rises. Subtropical Miami's frequent rainfall events will potentially cause more flooding and will increase polluted stormwater discharge into the Biscayne Bay through the two mangrove channels unless detention capacity is increased. Also, according to the FIU Division of Infrastructure, the FIU-BBC uses potable water for irrigation purposes.

2.2.1 Flooding due to Sea Level Rise, High Tides, and Groundwater Seepage

Sea-level rise could produce flooding at FIU-BBC in multiple ways. The first way is through direct surface inundation, especially during high tides. A second way is through the seepage due to the porous limestone medium that sits beneath the campus and the proximity to the Bay. Sea-level rise may also increase storm surge inundation that could occur during hurricane season. For instance, Hurricane Andrew (August 1992) made landfall in Miami as a category 5 hurricane, the largest on the Saffir-Simpson scale, producing wind gusts up to 165 mph and about 5.1 inches of rainfall (https://www.nhc.noaa.gov/1992andrew.html). For this hurricane, the predicted storm surge height in the FIU-BBC using the NOAA SLOSH model is 5 feet.

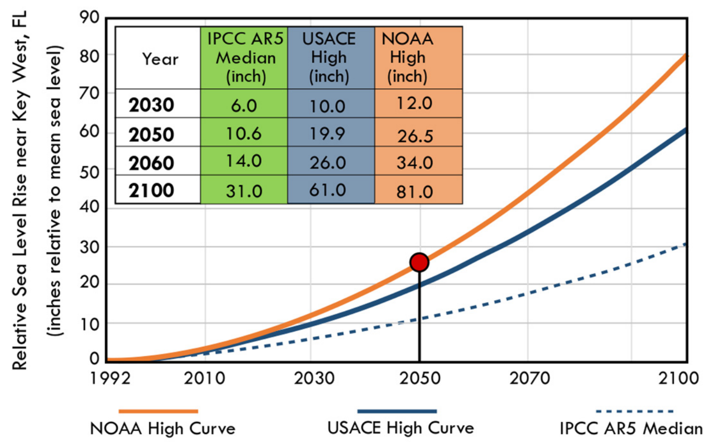

Figure 3. Unified Sea Level Rise Projections. These projections are referenced to mean sea level at the Key West tide gauge. The projection includes three global curves adapted for regional application: the median of the IPCC AR5 scenario as the lowest boundary (blue dashed curve), the USACE High curve as the upper boundary for the short term for use until 2060 (solid blue line), and the NOAA High curve as the uppermost boundary for medium and long term use (orange solid curve). (South Florida Regional Climate Change Compact, 2015)

The Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group provides a unified sea level rise projection scenario for the Southeast Florida (South Florida Regional Climate Change Compact, 2015). Figure 3 shows three sea-level rise projections with a large discrepancy among these curves, especially in the long term (~50-100 years). As figure 3 depicts, sea-level rise is projected to increase between 6 to 10 inches by 2030 and between 31 to 61 inches by 2100. Figure 3 also shows that the NOAA projection indicates larger increases for both short and long terms. Due to the large uncertainty of the long term sea-level rise projections, and in coordination with the FIU Facilities (Mr. Stuart Grant), we decided to design our green infrastructure for the medium term (2050). We also decided to use the NOAA projection curve, which estimates higher sea-level elevations for the short and long term. As a result, we used a sea-level rise of **2.2 ft (0.67m)** in our design. Figure 4 shows the inundation in the FIU BBC for the 2030 (1 ft), 2040 (1.5 ft), and 2050 (2.2 ft) sea-level rise scenarios.

To estimate the seepage flow both from the sea to the campus ponds (e.g., high tides) and from the ponds to the sea (e.g., extreme rainfall events), we performed seepage simulations using the GeoStudio Seep/w model (Krahn, 2004a). GeoStudio seep/w is a finite-element analysis tool intended for simulating groundwater flow in saturated and unsaturated porous media.

The foundational ground of the FIU-BBC was built in 1960 through the use of dredged material from the adjacent bay bottom, which consists of a mixture of sand and porous limestone. Due to such a porous substrate, there is significant water movement between the ponds and the Biscayne Bay. We used a hydraulic conductivity of 0.000015, which approximately represents the conductivity of such material (Charbeneau, 2006).

The infiltration rate (e.g., flow is from campus ponds to sea) modeling results for the 25-year return period rainfall and the 2050 sea-level rise scenario yields 0.0014 m^3/s per m^2 of surface flow area. Likewise, the exfiltration rate (flow is from sea to campus ponds) was calculated under high tide conditions assuming no rainfall, which gave 0.0023 $m^3/s/m^2$. Figures 5(a) and 5 (b) show the equipotential and flow line modeling results for the infiltration and exfiltration seepage for the largest existing wetland, respectively. The total surface flow area of the interconnected wetlands is about 2,000 m^2. The total estimated infiltration and exfiltration rates for all wetlands are 15 m^3/s and 57 m^3/s, respectively.

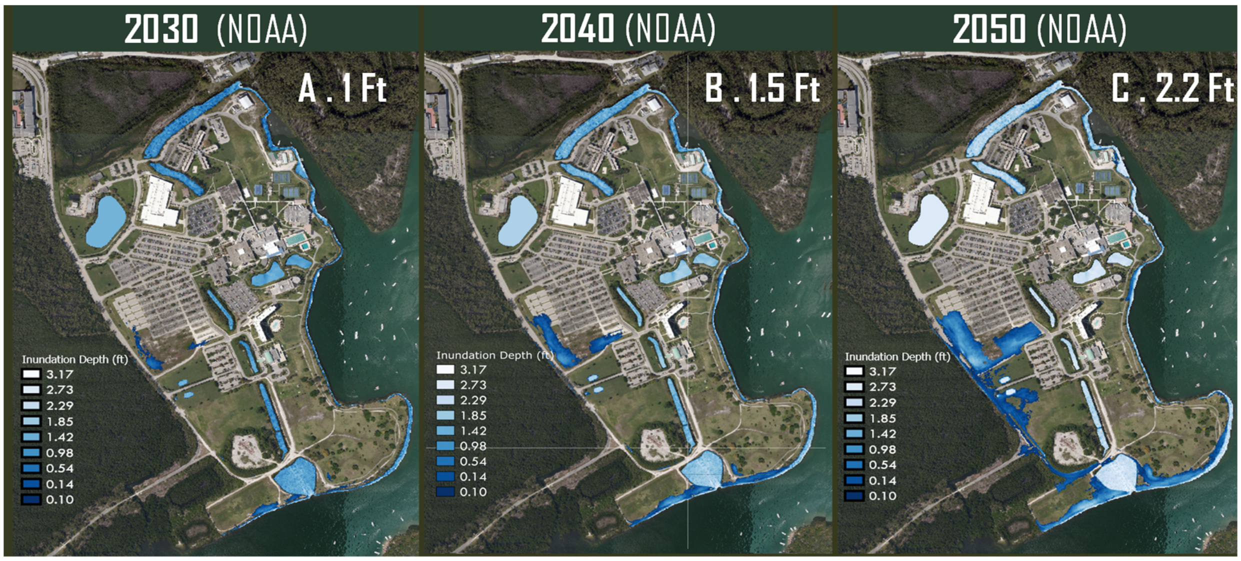

Figure 4. Inundation in the FIU-BBC for various sea-level rise scenarios. (A) 1ft (year 2030), (B) 1.5ft (year 2040), and (C) 2.2ft (year 2050)

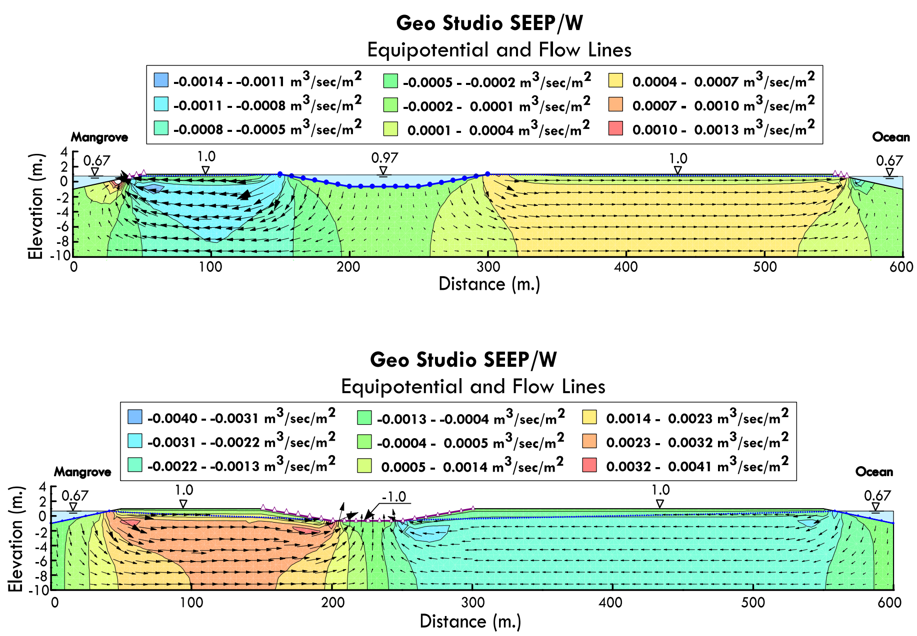

Figure 5. Equipotential and flow line modeling results for the largest existing pond. Black arrows indicate seepage flow directions. **A. Top.** Infiltration (from pond to the Biscayne Bay) and **B. Bottom.** Exfiltration (from Biscayne Bay to the pond).

According to the seepage analysis, water is infiltrated through the bottom and sides of the ponds in around 24 hours that fulfill the City of Miami regulations, which requires wet detention basins to be drained in a period of 14 days (Harper, 2005). Even though the existing ponds currently fulfill the regulations of the City of Miami in terms of the draining period, the storage capacity of the existing ponds will be significantly reduced in the future due to sea-level rise.

2.2.2 Rainfall Flooding

Rainfall flooding occurs when the ground cannot absorb rainwater. The combination of low ground elevation, high water table, porous limestone, and high rainfall frequency, contribute to an increased probability of pluvial flooding. In particular, the interplay between the seepage and sea-level rise will decrease the storage capacity of existing ponds on campus and will reduce the conveyance capacity of the existing mangrove drainage channels (e.g., backwater effects) making the FIU-BBC more susceptible to pluvial flooding, and hence, increase untreated stormwater discharge into the Biscayne Bay.

The flooding associated with rainfall was simulated using the United States Army Corps of Engineers (USACE), Hydrologic Engineering Center – River Analysis System (HEC-RAS), and Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) (Brunner, 1995; Feldman, 2000) models. The design rainfall used in the simulations, 24-hr 25-yr return period, is recommended by the stormwater guidelines of the City of Miami (SFWMD, 2014). The simulation results for the 24-hr 25-yr return period rainfall and the 2050 NOAA sea-level rise projections (2.2 ft sea-level rise) indicates that the maximum inundation will occur on the eastern part of the main channel with a maximum depth of 0.4m (1.2ft).

2.2.3 Stormwater Pollutant Discharge into the Biscayne Bay

The pollution load was estimated using the Spatially Integrated Model for Pollutant Loading Estimates (SIMPLE) (Schueler, 1987). The SIMPLE method classifies the average concentration of pollutants in stormwater runoff based on the land use type. The rainfall input for the model was calculated using the average of the last 10 years' (2008-2018) annual precipitation rates from the South Florida Water Management District (https://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu). Table 1 presents the typical concentrations of pollutants for the source areas that are observed in the FIU-BBC campus. Seven parameters that are typically found in urban stormwater runoff were used to characterize the pollutant load. These parameters are TSS (Total Suspended Solids), TP (Total Phosphorus), TN (Total Nitrogen), F. Coli, Cu (Copper), Pb (Lead), and Zn (Zinc). For illustration, Figure 6 shows the spatial distribution of lead (Pb) for the existing conditions (2019).

Table 1. Pollutant concentrations from non-point source areas

Constituent	TSS[1]	TP[2]	TN[3]	F Coli[1]	Cu[1]	Pb[1]	Zn[1]
Source Areas	(mg/l)	(mg/l)	(mg/l)	(1000 col/ml)	(µg/l)	(µg/l)	(µg/l)
Resid Roof	19	0.11	1.5	0.26	20	21	312
Comm. Roof	9	0.14	2.1	1.1	7	17	256
C/R Parking	27	0.15	1.9	1.8	51	28	139
Comm Street	468	-	-	12	73	170	450
Urban Highway	142	0.32	3	-	54	400	329
Lawns	602	2.1	9.1	24	17	17	50
Bannerman (1990), Claytor et al. (1996), Steuer et al. (1997), Waschbusch et al. (2000)							

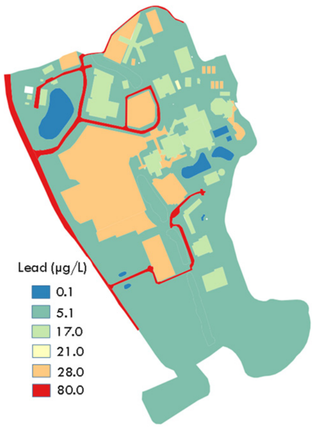

Figure 6. Spatial distribution of Pb (µg/L) in the FIU BBC campus for the existing conditions (December 2019).

3. Evaluated Solutions for Key Identified Challenges

We evaluated an array of green and conventional infrastructure implementations in order to address three key issues we identified for the 2050 NOAA sea-level rise projections (2.2 ft sea-level rise) by working closely with the FIU-BBC Facilities Department. These key issues are: (1) to eliminate the 24-hr, 25-yr return period rainfall flooding for the 2050 sea-level rise scenario; (2) to minimize pollutant discharge to the Biscayne Bay; and (3) to maximize rainwater reuse. The evaluated green and conventional infrastructure alternatives included dewatering of existing ponds and proposed wetlands through pumping, five new interconnected permeable wetlands to increase stormwater storage and also treatment of pollutants, addition of green roofs, vertical gardens, permeable walkway, and urban tree canopy, and a new lined wetland to store rainwater for the irrigation needs.

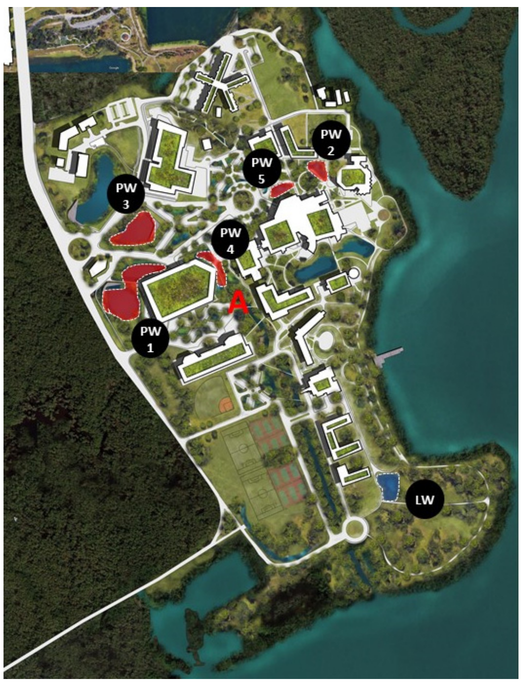

Figure 7. Proposed new wetlands. PW1, PW2, PW3, PW4, PW5 are permeable wetlands for infiltration and pollutant treatment. LW is a lined wetland for stormwater storage for irrigation purposes.

3.1 Dewatering of Existing Ponds and Proposed Wetlands Through Pumping

We performed a simulation of the seepage (exfiltration) for the existing ponds and proposed wetlands for the 2050 NOAA sea-level rise projections (2.2ft). As mentioned earlier, our seepage modeling results showed that the exfiltration rate, calculated under high tide conditions and assuming no rainfall, is about 57 m^3/s. The annual pumping costs including operation and maintenance for this flow rate is about three million dollars per year. The large costs associated with pumping when compared to the other green infrastructures, along with its ecological implications, led us to abandon this alternative.

3.2 Interconnected Artificial Wetlands and BioSwales

The majority of stormwater runoff at FIU-BBC is currently treated mostly using infiltration basins. The efficacy of this type of water quality treatment would decrease gradually, as the height of the water table increases. In order to treat stormwater before it is released into the Biscayne Bay, we evaluated the implementation of interconnected wetlands and bioswales. To eliminate the 24-hr, 25-yr return period rainfall flooding for the 2050 sea-level rise scenario, we determined that we would need extra net storage of about 12,000 m^3. To fulfill this requirement, we propose five new wetlands (PW1, PW2, PW3, PW4, and PW5) with an operational volume of 5,669m^3 (200,192ft^3), 528m^3 (18,638ft^3), 2,770m^3 (97,827ft^3), 2,072m^3 (73,177ft^3), and 1,301m^3 (45,956ft^3), respectively, and all with a side slope of 3H:1V. The location of the wetlands is shown in Figure 7. All five permeable wetlands would have weirs that would overflow into the swales, which in turn would convey the overflow water into the existing mangrove channels. All bioswales would be 1m deep and would cover a total area of approximately 1,446m^2 (51,065ft^2).

Similar to the existing conditions calculations, we utilized the USACE HEC-HMS and HEC-RAS hydrology-hydraulics models to estimate flooding for the projected 2050 NOAA sea-level rise scenario, with and without using the proposed wetlands as shown in Figure 8. The 25-year flood peak discharge for the projected 2050 scenario without the proposed five interconnected wetlands was computed to be 1.33 m^3/s (47.7cfs). The proposed five interconnected wetlands decreased the 25-year flood peak discharge to 58% of the pre-implementation of the wetlands as shown in Figure 9.

Following an in-depth analysis of the characteristics of South Florida's natural habitats, we also proposed to incorporate native flora for each of the constructed wetlands. The proposed native species are:

- Saw-Grass (*Cladium jamaicense*): a common species for Florida's fresh and brackish water wetlands. It provides food and shelter for birds and other wildlife.
- Bur Marigold (*Bidens laevis*): an emersed flowering plant from the daisy family. It is typically found in Florida's marshes.
- Florida Bladderwort (*Utricularia floridana*): a large affixed submersed carnivorous plant. The bladderwort gets its name from bladder-like traps that capture organisms like water fleas, nematodes, tadpoles, and mosquito larvae. Bladderworts have been reported growing in brackish and tidal marshes (Tiner, 2009).

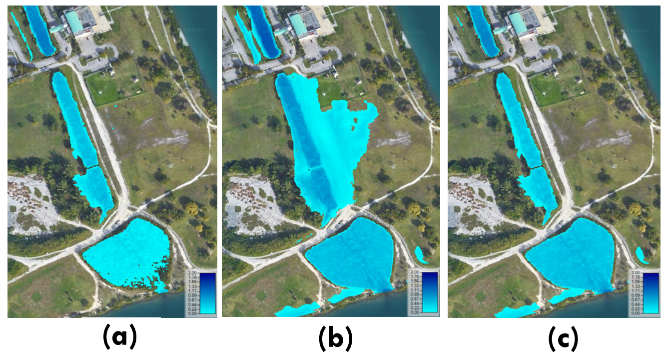

Figure 8. Flood inundation around the south mangrove channel for the 24-hr, 25-year return period for various scenarios. (a) Existing condition (2019) (b) 2050 NOAA sea-level rise projections **without** proposed wetlands (c) 2050 NOAA sea-level rise projections **with** proposed wetlands.

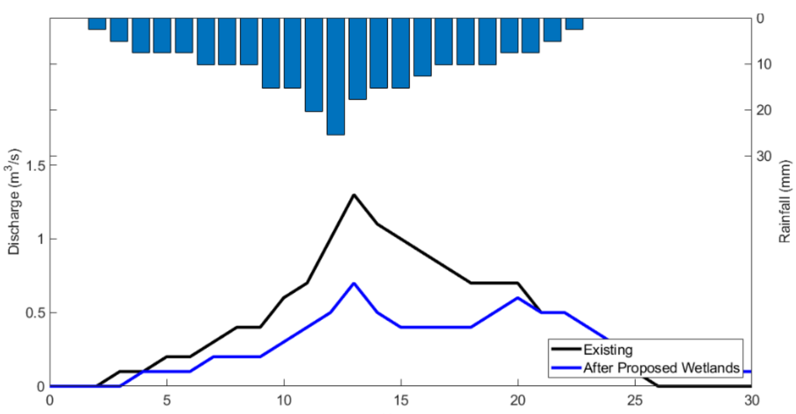

Figure 9. Flow hydrograph at the main channel inlet (point A in Figure 7) for the 2050 NOAA SLR projections with and without the implementation of the proposed wetlands.

Proposed BioSwales would include native flora, such as *Rondeletia leucophylla*, *Spartina bakeri*, *Zamia integrifolia*, and *Asclepias*, due to various benefits these plants offer, such as improved water quality, increased biodiversity, air-purification, and pollinator attraction. Bioswales need less maintenance than turf grass once established because they need less water and no fertilizer. Such native grasses and forbs are well-adapted to the environmental and soil conditions of South Florida (NRCS, 2005) and they resist local pests, disease, and weed infestations. As an aesthetic and recreational value, we also proposed to build a deck on one of the sides of the constructed wetlands, and a walkway around their perimeter.

3.3 Green Roofs

A green roof provides a buffer that cleans and treats stormwater runoff, reduces CO_2 emissions into the atmosphere, reduces heat island effects, regulates indoor temperatures, saves energy by reducing cooling costs for air-conditioned buildings, and promote campus biodiversity. Green roof temperatures can be 30–40°F lower than those of conventional roofs and can reduce city-wide ambient temperatures by up to 5°F (USGSA, 2011; Santamouris, 2014). In addition, green roofs can reduce building energy use by 0.7% compared to conventional roofs with annual savings of $0.23 per square foot of green roof's surface (USGSA, 2011; Sailor et al., 2012). Jim (2014) shows that green roofs help to maintain indoor temperatures throughout the day and reduces energy consumption by 19-40%. Due to extreme humidity and heat, we chose plants that are native to South Florida, known to consume less water, and good at filtering pollutants and providing wildlife habitat. The selected plants are Asteraceae, Poaceae, Lamiaceae and Solanaceae. Based on a green roof implementation of 419,530 ft^2, an average watering rate of 0.5 gals/ft^2/week, and a 28-week watering period (52 weeks minus 24 weeks for rainy season), the annual water demand for irrigating the green roofs is calculated as 5.9 million gallons. To irrigate green roofs and vertical gardens and also to minimize water consumption, we proposed the use of drip irrigation system. By supplying water directly onto the plant roots, the drip irrigation system eliminates water losses due to evaporation and runoff, when compared to sprinkler irrigation. In order to further maximize the use of rainwater falling on the roofs, we also proposed rainwater harvesting tanks next to the buildings with both vertical gardens and green roofs. The proposed tanks collect about 9.2 million gallons of rainwater per year, 5.9 million gallons of which (64%) would be used to irrigate the green roofs.

3.4 Vertical Gardens

We propose vertical gardens on the façades of the new parking garage in order to reduce cooling costs, CO_2 emissions into the atmosphere, heat island effect on wildlife and humans, direct stormwater runoff, and bring tremendous aesthetic value to the campus.

The vertical gardens consist of cage-like panels, measuring 5-10 ft tall, prepared with an irrigation framework. To prevent root attachments, the steel frames would be placed 12 inches away from the building façade. Due to its long lifespan and ability to grow in USDA hardiness zone 10B, the native Wild Allamanda (*Pentalinon luteum*) vine was selected as the vegetation for the vertical gardens. These vines grow up to 10ft tall and require full to partial sunlight. The vertical gardens would be implemented on the parking garage walls facing west and south. The parking garage wall heights and widths are 50ft and 360ft, respectively. The total area covered by the living wall is estimated to be 72,000 ft^2, consisting of 210 panels, 50 planters, and a total of 198 vines. Using a correlation between the average tree surface area and the maximum wall vegetation area, as well as the assumption that the new trees would absorb CO_2 at a rate of 48 lb/yr (McAliney, 1993), the CO_2 sequestered by the vertical gardens was calculated to be 9,504 lb/yr.

The irrigation of the vertical gardens would also utilize a drip irrigation system. The drip irrigation system would consist of 1gal/hr pressure-compensating emitters, soil humidity sensors, vertical mainlines from the storage water tanks to the highest planters, lateral lines scaling the building horizontally at vertical intervals of 10 ft, drip lines at every vine, slip ball valves, end caps, and pumps. Humidity sensors would be installed in each plant to detect dry soil conditions, enabling the irrigation system to deliver water automatically from the storage tanks when necessary. The emitters would deliver 1 gallon of water per week at a water pressure of 25 psi, except during Florida's rainy season (May-October). The pumping demands for each roof would be satisfied using a 1/6 HP submersible pump. Based on 198 vines, an average watering rate of 1 gal/vine/week, and a 28-week watering period (52 weeks excluding 24 weeks for rainy season), it was determined that we would only need 5,544 gallons of water per year. This water demand is only 0.06% of the annual amount collected in the rainwater harvesting tanks (9.2 million gallons).

3.5 Permeable Walkways and a Continuous Tree Canopy

It is well known that shade generated by tree canopy substantially reduces surface temperatures under the canopy. These cooler surfaces, in turn, reduce the heat transmitted into buildings or re-emitted into the atmosphere. (Akbari et al., 1997) measured maximum surface temperature reductions due to shade trees ranging from 20 to 45°F (11-25° C) for walls and roofs at two buildings. (Sandifer et al., 2002) examined the effects of vines on wall temperatures and found reductions of up to 36°F (20°C).

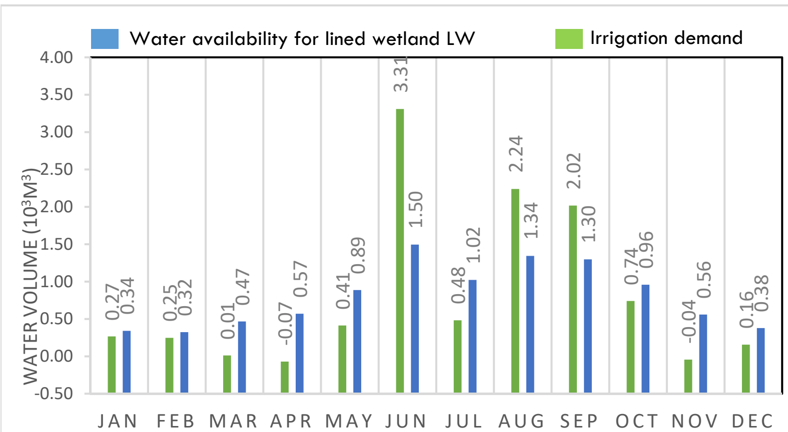

Figure 10. Annual water availability in wetland LW (green) and monthly irrigation demand for the existing and proposed tree canopy (blue).

To reduce the urban heat island effect caused by human activity, increase sequestration of carbon dioxide (CO_2), provide wildlife habitat, increase the level of comfort for pedestrians, and intercept rainfall that would otherwise travel to impervious surfaces and gather pollutants along the way, it was decided to use salt-tolerant tree canopies along the proposed walkway. The tree canopies that would be used include Red mangroves (*Rhizophora mangle*), Black mangroves (*Avicenna germinans*), sea grapes (*Coccoloba uvifera*) and Mahogany (*Swietenia mahagoni*). Mahogany is listed as a threatened species by the state of Florida (https://edis.ifas.ufl.edu/st608), therefore planting these trees around FIU-BBC would promote conservative actions. It was estimated that a total of 562 trees would be required based on a walkway length of 3.3 miles, an average tree spacing of 20 ft, and trees positioned on both sides of the walkway for 60% of the total length. The CO_2 sequestered by the 562 trees is estimated to be 17.3 tons/yr. The average canopy spread for the Mahogany is assumed to be 50ft (https://www.south-florida-plant-guide.com/mahogany-tree.html). On the basis of the respective canopy spreads, the circular shape of the canopies, and the quantity of each proposed tree, the total additional canopy area was estimated to be 8.7 acres. It is estimated that there will be a 56% increase in sequestrated CO_2 after the proposed new tree canopy.

Water for irrigating the tree canopy is supplied by the lined wetland (LW). The water deficit is supplied by the excess water collected at the rainwater harvesting tanks. To estimate the irrigation demands for the tree canopy, the SLIDE (Simplified Landscape Irrigation Demand Estimation) formulation from the ANSI/ASABE Standard S623 (Chilling et al., 2014) was used. The results suggest that the annual irrigation demand for the 17.3 acres existing and proposed tree canopy is about 3.2 million gallons. The results of the calculated monthly water demands, along with the water availability in the lined wetland are presented in Figure 10. As shown in this figure, during about half of the year, the stormwater runoff stored in the lined wetland LW (2.15 million gallons/yr) will not be able to fulfill the irrigation demands of the tree canopy. The water deficit for the irrigation of the tree canopy (1.05 million gallons/yr) will be supplied by the rainwater harvesting tanks, which will have a remaining volume of 2.7-million-gallons/yr after satisfying the irrigation demands of the green roofs and vertical gardens.

The water transfer from the lined wetland (LW) to the tree canopy irrigation network will be done using an automated siphon system developed by the members of our team (Qin et al., 2019). The proposed automated and remotely-operated siphon system (Figure 11) will release the optimal amount of water based on the tree canopy requirements. As shown in Figure 11, our siphon system consists of an integrated hardware/software framework that interfaces an actuated gate, water level sensors and sensor control/communication (3G/4G cellular connection). The entire setup requires a small amount of energy, which is largely satisfied with two 12-V batteries that are recharged by a single solar panel.

3.6 Parking Filtration Garden

This project also proposes additional filtration methods through the use of parking filtration gardens. The native plants in the parking gardens will filter stormwater runoff pollutants that would otherwise enter into the existing mangrove channels. The native plants will consist of *Zamia integrifolia, Rondeletia leucophylla, Asclepias, and Spartina bakeri*. The total area of the parking filtration garden is 124,361 ft^2. The calculations for the number of required plants is based on the assumption that 70% of the total area will consist of flora. The calculations determined that we would need a total of 363 plants for the parking filtration garden, which would reduce 69% of metals; 86% of TSS; 59% of TP; 38% of TN; 3% of F.Coli.

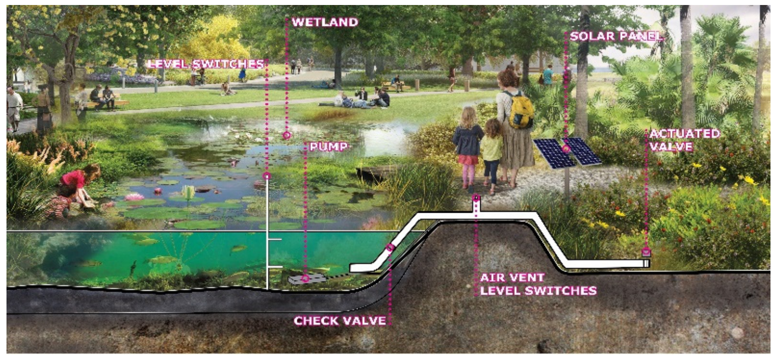

Figure 11. Schematic of our proposed automated and remotely-operated siphon system for water transfer from the lined wetland LW into the tree canopy irrigation network. For our siphon system in action, see https://www.youtube.com/watch?v=jYkEW8kxsXk

4. Reduction of Stormwater Pollutant to the Biscayne Bay

In order to evaluate the effectiveness of the combined green infrastructure, our team constructed an SWMM model to compare the runoff water quality under two scenarios, namely, the 2050 Pre-implementation and the 2050 Post-implementation. The nonpoint source pollutant data were taken from Table 1. The Event Mean Concentration method (Huber et al., 1975) was used to simulate the wash-off process of the non-source pollutants. The simulated event was the 24-hour, 25-return-period rainfall and the results were compared at the outlet of the south

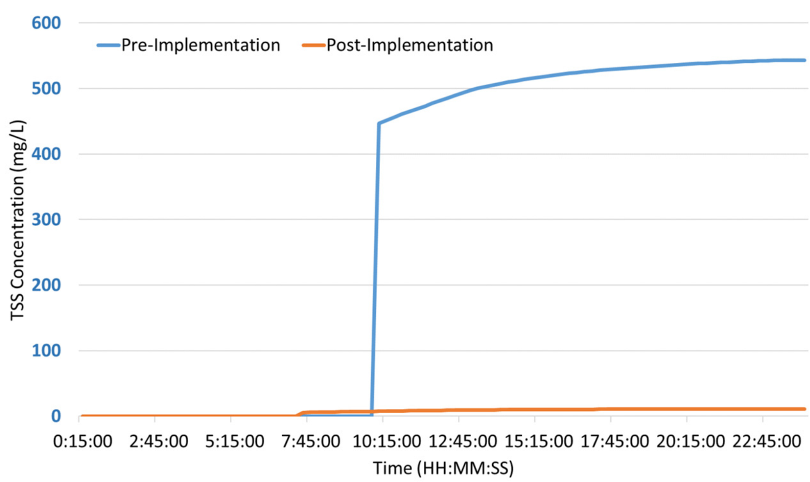

Figure 12. Wash-off TSS Concentration for the 24-hour, 25-return-period rainfall, 2050 pre-implementation and the 2050 post-implementation scenarios.

mangrove channel. Figure 12 illustrates the SWMM model results for the Total Suspended Solids (TSS) for the 2050 pre-implementation and the 2050 post-implementation scenarios. This figure shows that the proposed green infrastructure reduces the concentration of TSS at the mangrove channel outlet in about 98%. Likewise, the proposed green infrastructure reduces the concentration of heavy metals in about 12-20%.

5. Engagement with the Surrounding Community

An important goal of this project is to involve the FIU community and surrounding community of North Miami in the planning, design, implementation, and operation of the project. In order to coordinate with the FIU Facilities Department and engage the community with the project, an FIU-BBC Project Organization would be established. The organization would be responsible for hosting volunteer events for the community, contacting stakeholders for support, and spreading awareness about the importance of green infrastructure. Volunteer events would be held twice a year. The students, faculty, alumni, and community members would work together to conduct routine maintenance activities, such as the removal of invasive species from bioswales and rain gardens. The organization would also be responsible for gathering volunteers to construct the bioswales and rain gardens in order to reduce costs. As an educational contribution to the North Miami community, the organization would establish a semi-annual STEM Day, in which local K-12 schools would attend FIU-BBC to learn about green infrastructure practices. The event would begin with a tour of the stormwater alternatives implemented, followed by a hands-on activity in which students design their own solutions for the various stormwater issues faced in South Florida. An event like this would attract stakeholders and provide an opportunity for the Project Organization to establish partnerships and gain financial support for the project. For example, space for informational boots can be offered to stakeholders, such as engineering design firms, construction companies, non-profit organizations, and government agencies, in which they can make a financial donation to the project to secure a spot.

6. Construction

The wetlands would be constructed by excavating, backfilling, grading, diking and installing water control structures if specified (e.g., siphons). Wetland vegetation would be then planted or allowed to establish naturally. For the lined wetland LW, EPDM (Ethylene Propylene Diene Monomer) liner would be installed to avoid seawater seepage. To avoid puncturing the liner, bedding of engineered soil (a mixture of clay and sand) would be used. To promote vegetation in wetland LW, an engineered soil (a mixture of compost and natural soil) would be placed over the liner. The bioswales' construction would involve excavation, compaction, planting soil placement, pretreatment, and plant installation. The soil on the bottom and sides of the bioswale would be prepared (e.g., tilled) to promote optimal vegetation growth. The installation of green roofs includes waterproofing membranes, thermal insulation, a root barrier to protect the membrane, a drainage system, a filter cloth of polyester fiber mats, a growing medium of pumice, and vermiculite, organic material like straw, grass, sawdust, and plants. Finally, the rainwater harvesting tanks would be installed on the building sides after the green roof has been installed. The vertical garden setup includes a steel frame and drip irrigation installation and plantation. The plants would be installed after the plumbing for the drip irrigation has been installed.

7. Operation and Maintenance

Table 2 summarizes the recommended activities for the operation and maintenance of the proposed green infrastructure. All operation and maintenance activities will be the responsibility of the FIU

Facilities Department. The plan in Table 2 can be updated periodically to reflect specific system characteristics learned during the actual operation.

Table 2. Operation and Maintenance activities

Item	Activity	Schedule
Wetlands	Remove debris from trash rack and side slopes	Monthly
	Inlet/outlet inspection and cleanout	Monthly
	Forebay inspection and cleanout	Monthly-remove sediment every 7 years or when sediment volume exceeds 50% of storage volume
	Bank mowing and stabilization of eroded areas	Monthly
	Removal of invasive species, replant as necessary	Semi-Annually
	Inspect for structural damage	Annually
	Maintain Sediment level	Annually-remove at 20 years or when plants are being impacted
	Repair broken pipes	As needed
	Replace riprap that has been choked with sediment	As needed
	Pest control	As needed
BioSwales and Parking garden	Check for and remove trash and debris	Weekly
	Remove dead plant parts; replace any mulch where needed; thin any crowded/overgrown plants	Monthly
	Check for erosion and excessive ponding during storms	As needed
	Weed; water during drought; tidy up garden as needed	Weekly
	Plant/replant as needed	Monthly
	*Check pH 1x/year-adjust if necessary, as indicated by test	Once in a year
	Replace mulch where needed	Monthly
Rainwater Harvesting	Remove leaves and debris from gutters and downspouts	Semi-annually
	Remove any algae growth	Semi-annually
	Inspect and clean prescreening devices and first flush diverters	Quarterly
	Inspect and clean storage tank lids	Annually
	Inspect for and repair any clogging	Annually
	Inspect and repair mosquito screens	Annually
	Inspect tank and remove sediment build-up	Every 3 years
	Clear overhanging vegetation and trees over roof	Every 3 years
	Check integrity of backflow preventer	Every 3 years
	Inspect structural integrity of tank, pump, pipe, and electrical system and repair any damage	Every 3 years
	Replace damaged or defective system components	As needed
Green Roof	Weeding	Monthly
	Plant Replacement	As needed
	Irrigation	As needed
	Fertilization	As needed
	Spring cleanup	As needed
	Maintenance inspections	Monthly
	Soil test to manage soil for maximum plant vigor while also minimizing nutrient leaching	1/year
Vertical Garden	Prune and groom plants	Monthly
	Soil moisture level check	Monthly
	Inspect for pests and disease	Monthly
	Fertilize plants	Monthly

8. Construction Costs and Funding

As shown in Table 3, the construction cost of the proposed solutions is about $5 million in 2019 dollars. The focus of this project on water reuse, sustainability and green infrastructure create several funding prospects in the State of Florida. For example, Governor DeSantis and the Florida Legislature approved $40 million in statewide funding for developing water supply and water resource development projects. The application is opened each year through the **South Florida Water Management District (SFWMD) Coop Funding**. Another viable option is the **NRPA Great Urban Parks Campaign**, which provided total funding of $2 million in 2018. Another exciting opportunity is the **Florida Resilient Coastlines Program**, which offered total funding of $2.3 million in 2019. A larger funding source is the **Miami Forever Bond**, which up to date, has allocated $192 million towards sea level rise mitigation and flood prevention. The **Million Trees Miami Initiative** is another viable option, especially for the Urban Tree Canopy alternative. The **Nonpoint Source**

Funds of the **Florida Department of Environmental Protection** and the **Florida International University** are also potential providers of funding for the proposed solutions.

Table 3. Construction cost for proposed green infrastructure solutions

Alternative	Unit Price		Quantity		Total Cost	
Constructed Wetland					**$**	**115,812**
Saw-Grass	$0.5-$95	/plant	526	Plants	$	1,052
Bur Marigold	$0.5-$20	/plant	294	Plants	$	588
Florida Bladderwort	$0.5-$95	/plant	2307	Plants	$	4,614
Excavation/Compaction	$0.10	/ft³	871,580	ft³	$	87,158
Labor (10 people)	$35	/hr	640	Hr	$	22,400
BioSwale					**$**	**204,689**
Plants	$0.5-$20	/plant	93,038	Plants	$	186,076
Excavation/Compaction	$0.10	/ft³	102,130	ft³	$	10,213
Labor (10 people)	$35.00	/hr	240	Hr	$	8,400
Green Roof					**$**	**3,786,310**
Tubing	$14.98	/250 ft of tubing	2587	Ft	$	155
Slip Ball Valve with Tee Handle	$0.06	/valve	470	Valves	$	28
Emitters	$9.79	/30 emitters	277	emitters	$	90
End Caps	$0.67	/end cap	278	end caps	$	186
Green Roof Package	$9.00	/ft²	419530	ft²	$	3,775,770
Labor (4 people)	$35.00	/hr	288	Hr	$	10,080
Vertical Garden					**$**	**137,442**
Tubing	$14.98	/250 ft of tubing	3,240	ft	$	194
Slip Ball Valve with Tee Handle	$0.06	/valve	590	Valves	$	35
Emitters	$9.79	/30 emitters	348	Emitters	$	114
End Caps	$0.67	/end cap	475	End caps	$	318
Wild Allamanda Vines	$5.00	/vine	348	Vines	$	1,740
"Basic Wall System" Panels	$130.00	/panel	361	Panels	$	46,930
Singflo 24V Solar Water Pump	$85.00	/pump	24	Pumps	$	2,040
Soil Moisture Sensors	$5.95	/sensor	348	Sensors	$	2,071
Labor (4 workers)	$35.00	/hr	360	hr	$	50,400
Rainwater Harvesting					**$**	**158,145**
Tanks (5100 gal)	$10,095.00	/tank	15	Units	$	151,425
Labor (4 people)	$35.00	/hr	192	hr	$	6,720
Permeable Pavement					**$**	**330,570**
Pavers	$1,849.00	/600 ft²	104544	ft²	$	322,170
Labor (4 people)	$35.00	/hr	240	Hr	$	8,400
Tree Canopy					**$**	**306,400**
Plant	$100-125	/plant	2240	Plants	$	246,400
Labor (4 people)	$35.00	/hr	120	Hr	$	60,000
Irrigation Wetland					**$**	**214,131**
Saw-Grass	$0.5-$95	/plant	240	Plants	$	2,400
Bur Marigold	$0.5-$20	/plant	240	Plants	$	2,400
Florida Bladderwort	$0.5-$95	/plant	240	Plants	$	2,400
Excavation/Compaction	$0.07	/ft³	191166	ft³	$	13,382
Labor (10 people)	$35	/hr	120	Hr	$	15,000
Geotextile	$76	/100ft²	63722	ft²	$	48,429
EPDM (ethylene propylene diene monomer) liner	$72	/100ft²	63722	ft²	$	45,880
Automated Siphon System					**$**	**2,572**
Liquid Level Switch	$17.00	unit	8	Units	$	136
Bilge Pump	$30.97	unit	2	Units	$	62
6" Clear PVC Utility Swing Check Valve, Socket, EPDM	$124.71	unit	1	Units	$	125
Air vent with solenoid	$11.00	unit	2	Units	$	22
6" Solid PVC Schedule 40 Pipe	$3.96	/ft	60	Ft	$	238
6" Clear PVC Schedule 40 Pipe	$64.90	/ft	3	Ft	$	195
6" Schedule 40 PVC 90 Elbow Socket	$20.42	unit	3	Units	$	61
6" Schedule 40 PVC Tee Socket	$31.41	unit	1	Units	$	31
6" PVC Drain Cap	$4.89	unit	1	Units	$	5

6" Schedule 40 PVC Coupling Socket	$9.32	unit	1	Units	$ 9
6" Schedule 40 PVC Van Stone Flange Socket	$19.81	unit	1	Units	$ 20
6" EPDM Flange Gasket	$8.01	unit	1	Units	$ 8
Programming Logic Controller	$320	unit	1	Units	$ 320
VPN Router	$640	unit	1	Units	$ 640
Actuated Ball Valve	$700	unit	1	Units	$ 700
Parking Garden					**$ 256,285**
Plants	$0.5-$95	/plant	113290	Plants	$ 226,580
Excavation/Compaction	0.07	/ft³	124361	ft³	$ 8,705
Labor (5 people)	$35	/hr	120	Hr	$ 21,000
Total Cost					**$ 5,512,356**

9. Summary of Costs, Benefits, and Funding Options of Proposed Green Infrastructure Strategies

Table 4 presents a summary of the proposed green infrastructure strategies, the estimated costs for construction and maintenance, their anticipated benefits for the 2050 NOAA sea level rise projections, the timeline for their implementation and the possibilities for funding. For example, the proposed five permeable wetlands can remove 66-70% of the metals from the stormwater. This table can be used for prioritizing decision making of the best green infrastructure strategies to implement in the FIU-BBC campus. Our overall recommendation is to implement all proposed green infrastructure strategies, which would eliminate the 24-hr, 25-yr return period rainfall flooding for the 2050 NOAA sea level rise scenario.

Table 4. Summary of Costs, Benefits, and Funding Options of Proposed Green Infrastructure Strategies

Strategy	Estimated Costs		Anticipated Outcomes			Timeline for Implementation	Funding Options
	Const-ruction	Annual Maintenance	Stormwater Management	Water & Ecosystem Services	Social Value		
Permeable Wetlands	$129,810	$6,491	58% Peak discharge reduction (25-yr 24 hr rainfall)	66-70% metal removed in stormwater	Flood Reduction	1 year	FIU; SFWMD Coop Funding; Florida Resilient Coastlines Program; The Miami Forever Bond; Florida DEP: Nonpoint Source Funds
BioSwales	$20,283	$1,014			Flood Reduction		
Rainwater Harvesting	$158,145	$7,907	0.09% peak discharge reduction (1 year 24 hr rainfall)	Potable water supply	Irrigation Supply, Economic benefits	1 month	FIU; SFWMD Coop Funding; Florida Resilient Coastlines Program; The Miami Forever Bond;
Green Roof	$3,786,310	$189,315	64% peak discharge reduction (1 year 24 hour) @building	10% metal removed in stormwater; 2.2% increased CO_2 sequestration; 0.7% reduction energy use per building	Beautification	1 year	FIU; SFWMD Coop Funding; Florida Resilient Coastlines Program; The Miami Forever Bond;
Vertical Gardens	$137,442	$6,872	60% peak discharge reduction (1 year 24 hour) @building	1.8% increased CO_2 sequestration	Beautification	1 year	FIU; SFWMD Coop Funding; Florida Resilient Coastlines Program; The Miami Forever Bond;
Permeable Walkways	$330,570	$16,528	0.001% peak discharge reduction	Enhanced Infiltration	Beautification	1 year	FIU; SFWMD Coop Funding; Florida Resilient Coastlines Program; The Miami Forever Bond;
Urban Tree Canopy	$130,250	$6,513	0.01% peak discharge reduction	56% increased CO_2 sequestration	Enhanced Infiltration, Beautification	1 year	FIU; SFWMD Coop Funding; Florida Resilient Coastlines Program; The Miami Forever Bond; Million Trees Miami initiatives
Lined Irrigation Wetland + Automated Siphon System (6")	$2,572	$129	2.3% peak discharge reduction	Low-cost water transfer, 40 L/s	Irrigation supply, Economic benefits	1 month	FIU; SFWMD Coop Funding; Florida Resilient Coastlines Program; The Miami Forever Bond; Florida DEP: Nonpoint Source Funds

10. Conclusion

After a careful review of the FIU 2010-2020 Campus Master Plan, we envision a resilient future for our campus through the addition of eight green infrastructure initiatives for enhancing stormwater management at FIU-BBC. Collectively, all proposed green infrastructure strategies would fully eliminate flooding in the FIU-BBC campus associated with the 24-hr, 25-yr return period rainfall event and the 2050 sea-level rise projection. The annual removal efficiencies for the proposed combined green infrastructures are estimated to be approximately 84% for TSS, 51% for TN, 68% for TP, 80% for F.Coli, 42% for Pb, and 42% for Zn and. The proposed green infrastructure will also increase carbon sequestration in 60%. Sustainability goals outlined in the FIU Master Plan have been addressed, including water quality enhancements, flood mitigation, habitat restoration, reduced runoff, and water reuse. Every component of the proposed green infrastructure has been carefully analyzed, taking into account sustainable practices that would help restore South Florida's natural habitats, mitigate flooding, and enhance water quality while providing the FIU-BBC with recreational, academic, and aesthetic value. Given its location in a sensitive environment vulnerable to climate change, it is essential for the Florida International University to consider this proposal as a model for implementing green infrastructure practices in the near future.

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